PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G06F 11/14

A1

(11) International Publication Number: WO 99/46680

(43) International Publication Date: 16 September 1999 (16.09.99)

(21) International Application Number: PCT/US99/05071

(22) International Filing Date: 8 March 1999 (08.03.99)

(30) Priority Data:
09/037,652 10 March 1998 (10.03.98) US

(71) Applicant: NETWORK APPLIANCE, INC. [US/US]; 2770 San Tomas Expressway, Santa Clara, CA 95051 (US).

(72) Inventor: KLEINMAN, Steven; 157 El Monte Court, Los Altos, CA 94022 (US).

(74) Agent: LAW OFFICES OF STEVEN A. SWERNOFSKY; P.O. Box 390013, Mountain View, CA 94039-0013 (US).

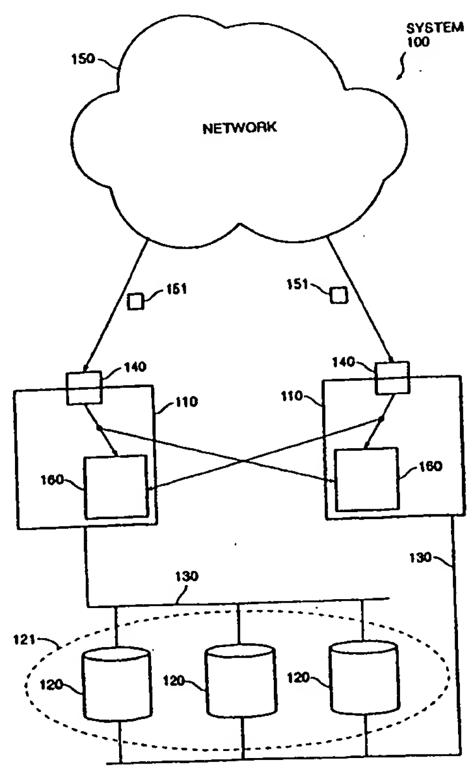
(81) Designated States: CA, CN, JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: HIGHLY AVAILABLE FILE SERVERS

(57) Abstract

The invention provides a storage system that is highly available even in the face of component failures in the storage system, and a method for operating that storage system. A first and a second file server each includes a file server request log for storing incoming file server requests. Both the first and second file servers have access to a common set of mass storage elements. Each incoming file server request is copied to both the first and second file servers; the first file server processes the file server request while the second file server maintains a copy in its file server request log. Each file server operates using a file system that maintains consistent state after each file server request. On failover, the second file server can perform those file server requests in its file server request log since the most recent consistent state. There is no single point of failure that prevents access to any individual mass storage element.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

Title of the Invention

Highly Available File Servers

Background of the Invention

1. *Field of the Invention*

The invention relates to storage systems.

2. *Related Art*

Computer storage systems are used to record and retrieve data. In some computer systems, storage systems communicate with a set of client devices, and provide services for recording and retrieving data to those client devices. Because data storage is important to many applications, it is desirable for the services and data provided by the storage system to be available for service to the greatest degree possible. It is therefore desirable to provide storage systems that can remain available for service even in the face of component failures in the storage system.

One known technique for provide storage systems that can remain available for service is to provide a plurality of redundant storage elements, with the property that when a first storage element fails, a second storage element is available to provide the services and the data otherwise provided by the first. Transfer of the function of providing services from the first to the second storage element is called "failover." The second storage element maintains a copy of the data maintained by the first, so that failover can proceed without substantial interruption.

A first known technique for achieving failover is to cause the second storage element to copy all the operations of the first. Thus, each storage operation completed by the first storage element is also completed by the second. This first known technique is subject to drawbacks: (1) It uses a substantial amount of processing power at the second storage element duplicating efforts of the first, most of which is wasted. (2) It slows the first storage element in confirming completion of operations, because the first storage element waits for the second to also complete the same operations.

A second known technique for achieving failover is to identify a sequence of checkpoints at which the first storage element is at a consistent and known state. On failover, the second storage element can continue operation from the most recent checkpoint. For example, the NFS (Network File System) protocol requires all write operations to be stored to disk before they are confirmed, so that confirmation of a write operation indicates a stable file system configuration. This second known technique is subject to drawbacks: (1) It slows the first storage element in performing write operations, because the first storage element waits for write operations to be completely stored to disk. (2) It slows recovery on failover, because the second storage element addresses any inconsistencies left by failure of the first between identified checkpoints.

Accordingly, it would be advantageous to provide a storage system, and a method for operating a storage system, that efficiently uses all storage system elements, quickly completes and confirms operations, and quickly recovers from failure of any storage element. This advantage is achieved in an embodiment of the invention in which the storage system implements frequent and rapid checkpoints, and in which the storage system rapidly distributes duplicate commands for those operations between checkpoints among its storage elements.

Summary of the Invention

The invention provides a storage system that is highly available even in the face of component failures in the storage system, and a method for operating that storage system. A first and a second file server each includes a file server request log for storing incoming file server requests. Both the first and second file servers have access to a common set of mass storage elements. Each incoming file server request is copied to both the first and second file servers; the first file server processes the file server request while the second file server maintains a copy in its file server request log. Each file server operates using a file system that maintains consistent state after each file server request. On failover, the second file server can perform those file server requests in its file server request log since the most recent consistent state.

In a second aspect of the invention, a file server system provides mirroring of one or more mass storage elements. Each incoming file server request is copied to both the first file server and the second file server. The first file server performs the file server requests to modify a primary set of mass storage elements, and also performs the same file server requests to modify a mirror set of mass storage elements. The mirror mass storage elements are disposed physi-

cally separately from the primary mass storage elements, such as at another site, and provide a resource in the event the entire primary set of mass storage elements is to be recovered.

Brief Description of the Drawings

Figure 1 shows a block diagram of a highly available file server system.

Figure 2 shows a block diagram of a file server in the file server system.

Figure 3 shows a process flow diagram of operation of the file server system.

Detailed Description of the Preferred Embodiment

In the following description, a preferred embodiment of the invention is described with regard to preferred process steps and data structures. However, those skilled in the art would recognize, after perusal of this application, that embodiments of the invention may be implemented using one or more general purpose processors (or special purpose processors adapted to the particular process steps and data structures) operating under program control, and that implementation of the preferred process steps and data structures described herein using such equipment would not require undue experimentation or further invention.

File Server Pair and Failover Operation

Figure 1 shows a block diagram of a highly available file server system.

A file server system 100 includes a pair of file servers 110, both coupled to a common set of mass storage devices 120. A first one of the file servers 110 is coupled to a first I/O bus 130 for controlling a first selected subset of the mass storage devices 120. Similarly, a second one of the file servers 110 is coupled to a second I/O bus 130 for controlling a second selected subset of the mass storage devices 120.

Although both file servers 110 are coupled to all of the common mass storage devices 120, only one file server 110 operates to control any one mass storage device 120 at any designated time. Thus, even though the mass storage devices 120 are each controllable by only

one file server 110 at a time, each of the mass storage devices 120 remains available even if one of its two associated file servers 110 fails.

In a preferred embodiment, the file server system 100 includes a pair of such file servers 110; however, in alternative embodiments, more than two such file servers 110 may be included in a single file server system 100.

In a preferred embodiment, the first I/O bus 130 and the second I/O bus 130 each include a mezzanine bus such as the PCI bus architecture.

In a preferred embodiment, the mass storage devices 120 include magnetic disk drives, optical disk drives, or magneto-optical disk drives. In alternative embodiments, however, other storage systems may be used, such as bubble memory, flash memory, or systems using other storage technologies. Components of the mass storage devices 120 are referred to as "disks," even though those components may comprise other forms or shapes.

Each mass storage device 120 can include a single disk or a plurality of disks. In a preferred embodiment, each mass storage device 120 includes a plurality of disks and is disposed and operated as a RAID storage system.

In a preferred embodiment, the first file server 110 is coupled to the second file server 110 using a common interconnect. The common interconnect provides a remote memory access capability for each file server 110, so that data can be stored at each file server 110 from a remote location. In a preferred embodiment, the common interconnect includes a Tandem "ServerNet" interconnect. The common interconnect is coupled to each file server 110 using a device controller coupled to an I/O bus for each file server 110.

The first file server 110 is coupled to a first network interface 140, which is disposed to receive file server requests 151 from a network 150. Similarly, the second file server 110 is coupled to a second network interface 140, which is also disposed to receive file server requests 151 from the network 150.

The first file server 110 includes a first server request memory 160, which receives the file server requests 151 and records them. In the event the first file server 110 recovers from a power failure or other service disruption, the outstanding file server requests 151 in

the first server request memory 160 are re-performed to incorporate them into a next consistent state of the file system maintained by the first file server 110.

Similarly, the second file server 110 includes a second server request memory 160, which receives the file server requests 151 and records them. In the event the second file server 110 recovers from a power failure or other service disruption, the outstanding file server requests 151 in the second server request memory 160 are re-performed to incorporate them into a next consistent state of the file system maintained by the second file server 110.

When the first file server 110 receives a file server request 151 from the network 150, that file server request 151 is copied into the first server request memory 160. The file server request 151 is also copied into the second server request memory 160 using remote memory access over the common interconnect. Similarly, when the second file server 110 receives a file server request 151 from the network 150, that file server request 151 is copied into the second server request memory 160. The file server request 151 is also copied into the first server request memory 160 using remote memory access over the common interconnect. Using remote memory access is relatively quicker and has less communication overhead than using a networking protocol.

In the event that either file server 110 fails, the other file server 110 can continue processing using the file server requests 151 stored in its own server request memory 160.

In a preferred embodiment, each server request memory 160 includes a nonvolatile memory, so those file server requests stored in either server request memory 160 are not lost due to power failures or other service interruptions.

The responding file server 110 processes the file server request 151 and possibly modifies stored files on one of the mass storage devices 120. The non-responding file server 110, partner to the responding file server 110, maintains the file server request 151 stored in its server request memory 160 to prepare for the possibility that the responding file server 110 might fail. In the event the responding file server 110 fails, the non-responding file server 110 processes the file server request 151 as part of a failover technique.

In a preferred embodiment, each file server 110 controls its associated mass storage devices 120 so as to form a redundant array, such as a RAID storage system, using inventions described in the following patent applications:

- Application Serial No. 08/471,218, filed June 5, 1995, in the name of inventors David Hitz et al., titled "A Method for Providing Parity in a Raid Sub-System Using Non-Volatile Memory", attorney docket number NET-004;

- Application Serial No. 08/454,921, filed May 31, 1995, in the name of inventors David Hitz et al., titled "Write Anywhere File-System Layout", attorney docket number NET-005;

- Application Serial No. 08/464,591, filed May 31, 1995, in the name of inventors David Hitz et al., titled "Method for Allocating Files in a File System Integrated with a Raid Disk Sub-System", attorney docket number NET-006.

Each of these applications is hereby incorporated by reference as if fully set forth herein. They are collectively referred to as the "WAFL Disclosures."

As part of the techniques shown in the WAFL Disclosures, each file server 110 controls its associated mass storage devices 120 in response to file server requests 151 in an atomic manner. The final action for any file server request 151 is to incorporate the most recent consistent state into the file system 121. Thus, file system 121 is in an internally consistent state after completion of each file server request 151. Thus, a file system 121 defined over the mass storage devices 120 will be found in an internally consistent state, regardless of which file server 110 controls those mass storage devices 120. Exceptions to the internally consistent state will only include a few of the most recent file server requests 151, which will still be stored in the server request memory 160 for both file servers 110. Those most recent file server requests 151 can be incorporated into a consistent state by performing them with regard to the most recent consistent state.

For any file server request 151, in the event the file server 110 normally responding to that file server request 151 fails, the other file server 110 will recognize the failure and perform a failover method to take control of mass storage devices 120 previously assigned to the failing file server 110. The failover file server 110 will find those mass storage devices

120 with their file system 121 in an internally consistent state, but with the few most recent file server requests 151 as yet unperformed. The failover file server 110 will have copies of these most recent file server requests 151 in its server request memory 160, and will perform these file server requests 151 in response to those copies.

File Server Node

Figure 2 shows a block diagram of a file server in the file server system.

Each file server 110 includes at least one processor 111, a program and data memory 112, the server request memory 160 (including a nonvolatile RAM), a network interface element 114, and a disk interface element 115. These elements are interconnected using a bus 117 or other known system architecture for communication among processors, memory, and peripherals.

In a preferred embodiment, the network interface element 114 includes a known network interface for operating with the network 150. For example, the network interface element 114 can include an interface for operating with the FDDI interface standard or the 100BaseT interface standard.

After failover, the file server 110 responds to file server requests directed to either itself or its (failed) partner file server 110. Each file server 110 is therefore capable of assuming an additional network identity on failover, one for itself and one for its failed partner file server 110. In a preferred embodiment, the network interface element 114 for each file server 110 includes a network adapter capable of responding to two separate addresses upon instruction by the file server 110. In an alternative embodiment, each file server 110 may have two such network adapters.

In a preferred embodiment, the disk interface element 115 includes a known disk interface for operating with magnetic, optical, or magneto-optical disks, that has two independent ports with each port coupled to a separate file server 110, such as the FC-AL interface. This helps prevent failure of one file server 110 from affecting low-level operation of the other file server 110.

In a preferred embodiment, the bus 117 includes at least a memory bus 171 and the mezzanine bus 130. The memory bus 171 couples the processor 111 and the program and data memory 112. The mezzanine bus 130 couples the network interface element 114 and the disk interface element 115. The memory bus 171 is coupled to the mezzanine bus 130 using an I/O controller 173 or other known bus adapter technique.

In a preferred embodiment, each disk in the mass storage 120 is statically assigned to either the first file server 110 or the second file server 110, responsive to whether the disk is wired for primary control by either the first file server 110 or the second file server 110. Each disk has two control ports A and B; the file server 110 wired to port A has primary control of that disk, while the other file server 110 only has control of that disk when the other file server 110 has failed.

Operation Process Flow

Figure 3 shows a process flow diagram of operation of the file server system.

A method 300 is performed by the components of the file server 100, and includes a set of flow points and process steps as described herein.

At a flow point 310, a device coupled to the network 150 desires to make a file system request 151.

At a step 311, the device transmits the file system request 151 to the network 150.

At a step 312, the network 150 transmits the file server request 151 to the file server 110.

At a step 313, a first file server 110 at the file server system 100 receives the file server request 151. The first file server 110 copies the file server request 151 into the first server request memory 160, and also copies the file server request 151 into the second server request memory 160 using the common interconnect. The target of the copying operation in the second server request memory 160 is to an area reserved for this purpose. The copying operation requires no further processing by the second file server 110, and the second file server 110 does not normally process or respond to the file server request 151.

At a step 314, the first file server 110 responds to the file server request 151.

At a flow point 320, the file server request has been successfully processed.

In a second aspect of the invention, the first file server 110 provides mirroring of one or more of its mass storage devices 120.

As with the first aspect of the invention, each incoming file server request is copied to both the first file server 110 and the second file server 110. The first file server 110 performs the file server requests to modify one or more primary mass storage devices 120 under its control. The first file server 110 also performs the file server requests to modify a set of mirror mass storage devices 120 under its control, but located distant from the primary mass storage devices 120. Thus, the mirror mass storage devices 120 will be a substantial copy of the primary mass storage devices 120.

The mirror set of mass storage devices 120 provide a resource in the event the entire primary set of mass storage devices 120 is to be recovered, such as if a disaster befalls the primary set of mass storage devices 120.

At a flow point 330, the first file server 110 in the file server system 100 fails.

At a step 331, the second file server 110 in the file server system 100 recognizes the failure of the first file server 110.

In a preferred embodiment, the second file server 110 performs the step 331 in the following manner:

- Each file server 110 maintains two disks of its mass storage devices 120 (thus, there are a total of four such disks for two file servers 110) for recording state information about the file server 110. There are two such disks (called "mailbox disks") so that one can be used as primary storage and one can be used as backup storage. If one of the two mailbox disks fails, the file server 110 using that mailbox disk designates another disk as one of its two mailbox disks.

- Each file server 110 maintains at least one sector on each mailbox disk, on which the file server 110 periodically writes state information. Each file server 110 also sends its state information to the other file server 110 using the interconnect using remote memory access. The state information written to the mailbox disks by each file server 110 changes with each update.

- Each file server 110 periodically reads the state information from at least one of the mailbox disks for the other file server 110. Each file server 110 also receives state information from the other file server 110 using the interconnect using remote memory access.

- Each file server 110 recognizes if the other file server 110 has failed by noting that there has been no update to the state information on the mailbox disks for the other file server 110.

In a preferred embodiment, the second file server 110 determines whether failure of the first file server 110 is a hardware error or a software error, and only recognizes failure of the first file server 110 for hardware errors. In alternative embodiments, the second file server 110 may recognize failure of the first file server 110 for software errors as well.

At a step 332, the second file server 110 seizes control of all mass storage devices 120 previously assigned to the first file server 110. Due to the nature of the techniques shown in the WAFL Disclosures, the file system 121 defined over those mass storage devices 120 will be in an internally consistent state. All those file server requests 151 marked completed will have been processed and the results incorporated into storage blocks of the mass storage devices 120.

In normal operation, neither file server 110 places reservations on any of the mass storage devices 120. In the step 332 (only on failover), the second file server 110 seizes control of the mass storage devices 120 previously controlled by the first file server 110, and retains control of those mass storage devices 120 until it is satisfied that the first file server 110 has recovered.

When the first file server 110 recovers, it sends a recovery message to the second file server 110. In a preferred embodiment, the second file server 110 relinquishes control of the seized mass storage devices 120 by operator command. However, in alternative embodiments,

the second file server 110 may recognize the recovery message from the first file server 110 and relinquish control of the seized mass storage devices 120 in response thereto.

At a step 333, the second file server 110 notes all file server requests 151 in the area of its server request memory 160 that were copied there by the first file server 110. Those file server requests 151 whose results were already incorporated into storage blocks of the storage devices 120 are discarded.

At a step 334, when the second file server 110 reaches its copy of each file server request 151, the second file server 110 processes the file server request 151 normally.

At a flow point 340, failover from the first file server 110 to the second file server 110 has been successfully handled.

Alternative Embodiments

Although preferred embodiments are disclosed herein, many variations are possible which remain within the concept, scope, and spirit of the invention, and these variations would become clear to those skilled in the art after perusal of this application.

Claims

1. A file server system including

a first file server including a file server change memory;

a second file server including a file server change memory;

a mass storage element;

said first file server and said second file server being coupled to said mass storage element;

means for copying a descriptor of a file system change to both said first and second file servers, whereby said first file server processes said file system change while said second file server maintains its copy of said descriptor in its file server change memory; and

means for said second file server to perform a file system change in its file server change memory in response to a service interruption by said first file server.

2. A system as in claim 1, including at least one said mass storage element for each said file server.

3. A system as in claim 1, wherein a first said file server is disposed for processing said file system changes atomically, whereby a second said file server can on failover process exactly those file system changes not already processed by said first file server.

4. A system as in claim 1, wherein a first said file server is disposed to respond identically to service interruptions for itself and for a second said file server.

5. A system as in claim 1, wherein at least one said file server is disposed to delay output to said mass storage element without delaying a response to file system changes.

6. A system as in claim 1, wherein at least one said file server responds to a file system change before committing a result of said file system change to mass storage.

7. A system as in claim 1, wherein

each one of said file servers is coupled to at least a portion of said file server change memory using local memory access; and

each one of said file servers is coupled to at least a portion of said file server change memory using remote memory access.

8. A system as in claim 1, wherein said descriptor includes a file server request.

9. A system as in claim 1, wherein said file server change memory includes a disk block.

10. A system as in claim 1, wherein said file server change memory includes a file server request.

11. A system as in claim 1, wherein said file server change memory is disposed to delay output to said mass storage element without delaying a response to file server requests.

12. A system as in claim 1, wherein

said mass storage element includes a file storage system;

each said file server is disposed for leaving said file storage system in an internally consistent state after processing file system changes;

said internally consistent state is associated with a set of completed file system changes;

said set of completed file system changes is identifiable by each said file server.

13. A system as in claim 1, wherein said mass storage element includes a file storage system and each said file server is disposed for leaving said file storage system in an internally consistent state after processing each said file system change.

14. A file server system as in claim 1, wherein

said mass storage element includes a primary mass storage element and a mirror mass storage element; and

said first file server processes said file system change for both said primary mass storage element and said mirror mass storage element.

15. A system as in claim 1, wherein said means for copying includes access to at least one of said first and second file server change memories using a NUMA network.

16. A system as in claim 1, wherein said means for copying includes remote memory access to at least one of said first and second file server change memories.

17. A system as in claim 1, wherein said means for said second file server to perform a file server request in its file server change memory is also operative in response to a service interruption by said second file server.

18. A file server system including

a first file server coupled to a first set of mass storage devices;

a second file server coupled to a second set of mass storage devices;

a server change memory;

said first file server disposed for receiving a file server request and in response thereto copying a descriptor of a file system change into said server change memory; and

said first file server disposed for processing said file system change for both said first set of mass storage devices and for at least one said mass storage device in said second set.

19. A system as in claim 18, wherein

said second file server is disposed for receiving a file server request and in response thereto copying a descriptor of a file system change into said server change memory; and

said second file server is disposed for processing said file system change for both said second set of mass storage devices and for at least one said mass storage device in said first set.

20. A system as in claim 18, wherein said server change memory includes a disk block.

21. A system as in claim 18, wherein said server change memory includes a file server request.

22. A system as in claim 18, wherein said server change memory includes a first portion disposed at said first file server and a second portion disposed at said second file server.

23. A system as in claim 18, wherein

said server change memory includes a first portion disposed at said first file server and a second portion disposed at said second file server; and

said first file server is disposed for copying said descriptor into both said first portion and said second portion.

24. A system as in claim 18, wherein

said server change memory includes a first portion disposed at said first file server and a second portion disposed at said second file server; and

said first file server and said second file server are each disposed for copying said descriptor into both said first portion and said second portion.

25. A system as in claim 18, wherein said server change memory is disposed to delay output to said mass storage element without delaying a response to file server requests.

26. A file server system including

a plurality of file servers, said plurality of file servers coupled to a mass storage element and at least one file server change memory;

each said file server disposed for receiving a file server request and in response thereto copying a descriptor of a file system change into said file server change memory; and

each said file server disposed for responding to a service interruption by performing a file system change in said file server change memory.

27. A system as in claim 26, including at least one said mass storage element for each said file server.

28. A system as in claim 26, including at least one said server change memory for each said file server.

29. A system as in claim 26, wherein a first said file server is disposed for processing said file system changes atomically, whereby a second said file server can on failover process exactly those file system changes not already processed by said first file server.

30. A system as in claim 26, wherein a first said file server is disposed to respond identically to service interruptions for itself and for a second said file server.

31. A system as in claim 26, wherein at least one said file server delays output to said mass storage element without delaying a response to file server requests.

32. A system as in claim 26, wherein at least one said file server responds to a file system change before committing a result of said file system change to mass storage.

33. A system as in claim 26, wherein

each one of said file servers is coupled to at least a portion of said file server change memory using local memory access; and

each one of said file servers is coupled to at least a portion of said file server change memory using remote memory access.

34. A system as in claim 26, wherein each said file server is disposed for copying said descriptors using a NUMA network.

35. A system as in claim 26, wherein each said file server is disposed for copying said descriptors using remote memory access.

36. A system as in claim 26, wherein said file server change memory includes a disk block.

37. A system as in claim 26, wherein said file server change memory includes a file server request.

38. A system as in claim 26, wherein said file server change memory is disposed to delay output to said mass storage element without delaying a response to file server requests.

39. A system as in claim 26, wherein said mass storage element includes a file storage system and each said file server is disposed for leaving said file storage system in an internally consistent state after processing each said file system change.

40. A system as in claim 26, wherein

said mass storage element includes a file storage system;

each said file server is disposed for leaving said file storage system in an internally consistent state after processing file system changes;

said internally consistent state is associated with a set of completed file system changes;

said set of completed file system changes is identifiable by each said file server.

41. A file server system as in claim 26, wherein

said mass storage element includes a primary mass storage element and a mirror mass storage element; and

said first file server processes said file system change for both said primary mass storage element and said mirror mass storage element.

42. A method of operating a file server system, said method including steps for

responding to an incoming file server request by copying a descriptor of a file system change to both a first file server and a second file server;

processing said file system change at said first file server while maintaining said descriptor copy at said second file server; and

performing, at said second file server, a file system change in response to a copied descriptor and a service interruption by said first file server.

43. A method as in claim 42, including steps for associating a first file server and a second file server with a mass storage element.

44. A method as in claim 42, including steps for delaying output by at least one said file server to said mass storage system without delaying a response to file system changes.

45. A method as in claim 42, wherein a first said file server is disposed for processing said file system changes atomically, whereby a second said file server can on failover process exactly those file system changes not already processed by said first file server.

46. A method as in claim 42, wherein a first said file server is disposed to respond identically to service interruptions for itself and for a second said file server.

47. A method as in claim 42, wherein at least one said file server responds to a file system change before committing a result of said file system change to mass storage.

48. A method as in claim 42, wherein

each said file server includes a file server change memory;

each one of said file servers is coupled to at least a portion of said file server change memory using local memory access; and

each one of said file servers is coupled to at least a portion of said file server request memory using remote memory access.

49. A method as in claim 42, wherein said file server change memory includes a disk block.

50. A method as in claim 42, wherein said file server change memory includes a file server request.

51. A method as in claim 42, wherein said file server change memory is disposed to delay output to said mass storage element without delaying a response to file server requests.

52. A method as in claim 42, wherein said mass storage element includes a file storage system and each said file server is disposed for leaving said file storage system in an internally consistent state after processing each said file system change.

53. A method as in claim 42, wherein said steps for performing a file system change in response to a copied descriptor are also operative in response to a service interruption by said second file server.

54. A method as in claim 42, wherein said steps for processing includes steps for processing said file system change at both a primary mass storage element and a mirror mass storage element.

55. A method of operating a file server system, said method including steps for

receiving a file server request at one of a plurality of file servers and in response thereto copying a descriptor of a file system change into a server change memory;

processing said file system change for both a first set of mass storage devices coupled to a first one said file server and for at least one said mass storage device in a second set of mass storage devices coupled to a second one said file server.

56. A method as in claim 56, wherein said descriptor includes a file server request.

57. A method as in claim 56, wherein said server change memory includes a disk block.

58. A method as in claim 56, wherein said server change memory includes a file server request.

59. A method as in claim 56, wherein said server change memory includes a first portion disposed at said first file server and a second portion disposed at said second file server.

60. A method as in claim 56, wherein said server change memory includes a first portion disposed at said first file server and a second portion disposed at said second file server; and wherein said steps for copying include steps for copying said descriptor into both said first portion and said second portion.

61. A method as in claim 56, wherein said server change memory includes a first portion disposed at said first file server and a second portion disposed at said second file server; and said steps for copying include steps for copying said descriptor into both said first portion and said second portion by either of said first file server or said second file server.

62. A method as in claim 56, wherein said server change memory is disposed to delay output to said mass storage element without delaying a response to file server requests.

63. A method as in claim 56, wherein

said steps for receiving include receiving a file server request at either said first file server or said second file server, and said steps for copying said descriptor include copying by either said first file server or said second file server; and including steps for

processing said file system change for both said second set of mass storage devices and for at least one said mass storage device in said first set.

64. A method of operating a file server system, said method including steps for

receiving a file server request at one of a plurality of file servers and in response thereto copying a descriptor of a file system change into a file server change memory; and

responding to a service interruption by performing a file system change in response to a descriptor in said file server change memory.

65. A method as in claim 65, including steps for associating a plurality of file servers with at least one mass storage element and at least one file server change memory.

66. A method as in claim 65, including steps for delaying output to a mass storage element without delaying a response to file server requests.

67. A method as in claim 65, including steps for leaving a file storage system on said mass storage element in an internally consistent state after processing each said file system change.

68. A method as in claim 65, including steps for

leaving a file storage system on said mass storage element in an internally consistent state after processing file system changes;

associating said internally consistent state with a set of completed file system changes; and

identifying said set of completed file system changes by at least one said file server.

69. A method as in claim 65, including steps for performing said received file server request at both a primary mass storage element and a mirror mass storage element.

70. A method as in claim 65, including steps for

processing said file system changes atomically at a first said file server; and

on failover processing exactly those file system changes not already processed by said first file server.

71. A method as in claim 65, including steps for responding identically at a first said file server to service interruptions for itself and for a second said file server.

72. A method as in claim 65, wherein said file server change memory includes a disk block.

73. A method as in claim 65, wherein said file server change memory includes a file server request.

74. A method as in claim 65, wherein said file server change memory is disposed to delay output to said mass storage element without delaying a response to file server requests.

75. A method as in claim 65, including steps for responding to a file system change before committing a result of said file system change to mass storage at one said file server.

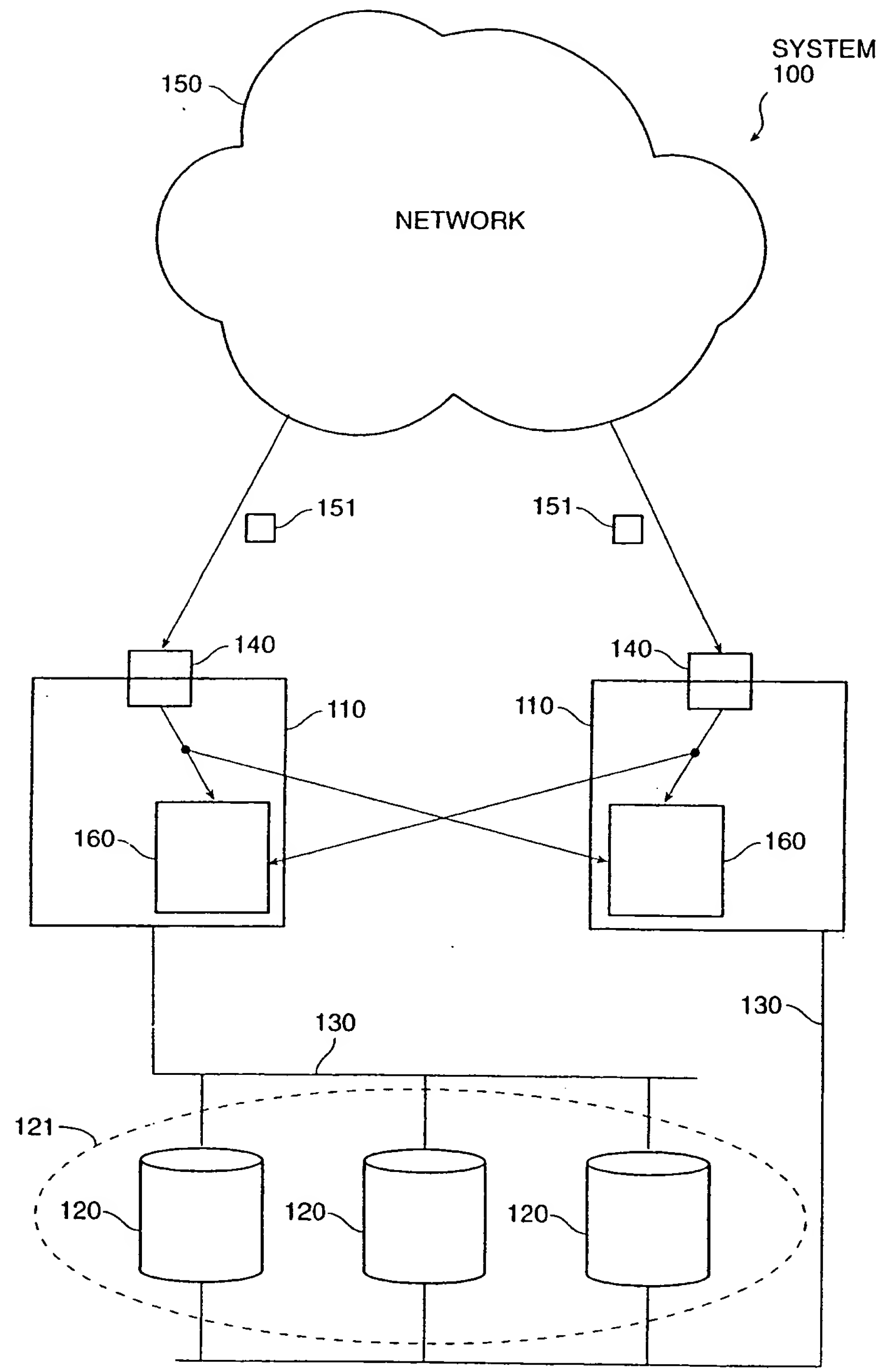

SYSTEM
100
150
NETWORK
151
151
140
140
110
110
160
160
130
130
130
121
120
120
120

FIG. 1

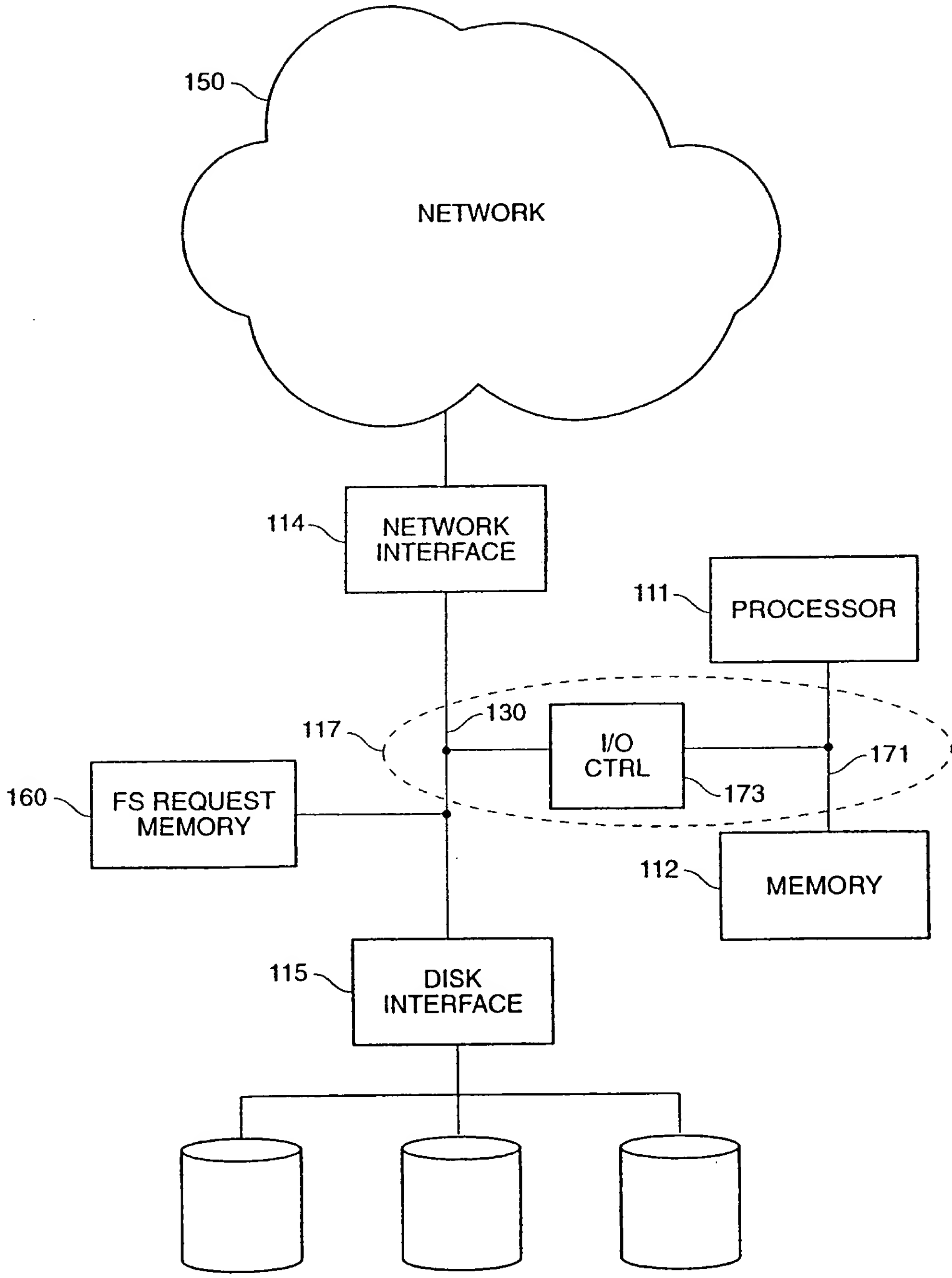

150
NETWORK
114
NETWORK INTERFACE
111
PROCESSOR
117
130
I/O CTRL
171
173
160
FS REQUEST MEMORY
112
MEMORY
115
DISK INTERFACE

FIG. 2

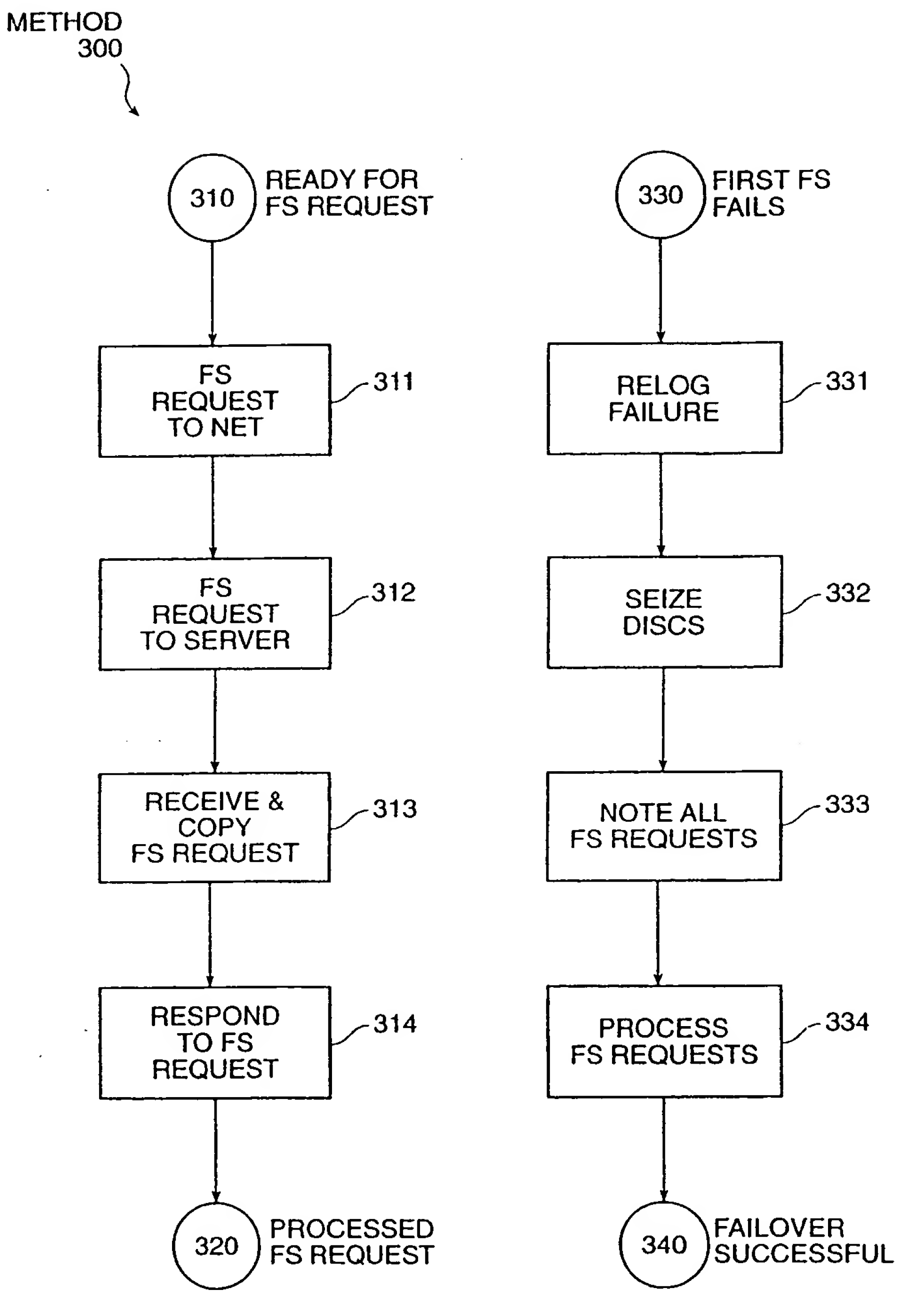

METHOD
300
310
READY FOR
FS REQUEST
FS
REQUEST
TO NET
311
FS
REQUEST
TO SERVER
312
RECEIVE &
COPY
FS REQUEST
313
RESPOND
TO FS
REQUEST
314
320
PROCESSED
FS REQUEST
330
FIRST FS
FAILS
RELOG
FAILURE
331
SEIZE
DISCS
332
NOTE ALL
FS REQUESTS
333
PROCESS
FS REQUESTS
334
340
FAILOVER
SUCCESSFUL

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/05071

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G06F11/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 720 029 A (KERN ET AL.) 17 February 1998 (1998-02-17) column 5, line 13 - line 35	1-75
A	US 5 504 883 A (COVERSTON ET AL.) 2 April 1996 (1996-04-02) claim 1	1-75

[ ] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 July 1999	05/08/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Corremans, G

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/05071

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5720029 A	17-02-1998	NONE	
US 5504883 A	02-04-1996	NONE	